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ON THE PROBLEM OF NEON

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From the results of experimental work done at
Chalk River in 1961 (Kuehner, Gove, Litherland, Clark,
and Almqvist, 1961), it appears that the capture cross-
section for the $O^{16} + He^4 \rightarrow Ne^{20} + \gamma$ reaction is
unusually small and that the isotope Ne^{20} will not be
produced during the helium burning stage of a star
unless the burning temperature is rather high
$(T > 2.5 \times 10^8\ ^\circ K)$. The purpose of the present note is
to point out that with any reasonable assumption for
the rate of $Ne^{20} + He^4 \rightarrow Mg^{24} + \gamma$, one finds the Ne^{20}
to be rapidly destroyed in all physical conditions
where it is produced to any extent.

This isotope never becomes the main outcome of the
helium burning stage. In Fig. 1 we have plotted in the
density temperature plane, the lines of isoabundances
of Ne^{20}, where this element reaches its maximum abun-
dance.* The burning stages have been assumed to occur at
fixed density and temperature. More realistic models
yield essentially the same results.

* Here the factor $\theta_\alpha{}^2$ for the 7.118 Mev level in O^{16}

  was chosen as $\theta_\alpha{}^2 = 0.1$. If we choose $\theta_\alpha{}^2 = 1.0$, we

  get the same pattern, but shifted by a factor of ten in

  density (the peak has the same height, but is situated

  at $\rho = 3 \times 10^3$ instead of 3×10^2 gr/cm^3, while the tempera-

  ture remains the same ($T_c = 3.4$).

From this analysis it seems reasonable to state that the helium burning stage is not the main source of the Ne^{20} isotope in the universe. Indeed the cosmic abundance of Ne^{20} is only from 2 to 4 times smaller than the combined abundance of carbon and oxygen.

A possible confirmation of that hypothesis may come from the following observational evidence. The planetary nebula typically have ratios of neon to oxygen which are about 10 times smaller than normal (Aller, private communication). It does not appear unreasonable to argue that if there are any settings in our universe where we may hope to see the products of helium burning reactions, unadulterated by nuclear processes associated with further stellar evolution, it is, indeed, in the gases which form the bulk of the planetary nebulae. On the other hand, the hot sub-dwarfs (very likely in advanced evolutionary stages) appear to have normal abundances of Ne^{20} (Wallerstein, private communication). The B stars (hot main sequence stars) also have normal abundances, but what that really means is far from being clear.

The neon atom can be made in other circumstances. If C^{12} is made in reasonable abundance during the helium

burning stage (this will be the case for stars of less than $\simeq$ 30 solar masses), then the star may go through a carbon burning stage. One important product of the carbon stage is Ne^{20}. Further, helium burning at temperature above one billion degrees--such as may occur in supernova--but below two billion degrees (as the Ne^{20} would then be photodisintegrated) may yield this isotope in reasonable amount.

To go one step further, we shall make use of an argument which is often introduced in similar discussions, which appears valid, but which in the long run may be discarded as irrelevant. The argument goes like this: the process by which enriched matter is returned to the interstellar gases involves the emission of some of the shells of well-determined elements made previously in the star. Since the emission of a deep shell is necessarily accompanied by a shallower one, but not vice versa, the galactic enrichment of the products of hydrogen burning should be larger than galactic enrichment of the products of helium burning, etc.

Making use of this argument and coupling it with the fact that Ne^{20} appears to be made in rather special circumstances of advanced stellar evolution, we want to suggest that

the near equality of the oxygen and neon abundance in our universe presents a problem of importance. Any reasonable theory of nuclear synthesis should match the challenge of producing enough neon to explain the observational evidence.

We have ignored in this analysis the possibility that Ne^{22} be of importance. Ne^{22} can be made in the helium burning stage from the N^{14} left over after a previous CNO cycle. However, 1) Ne^{22} would be at best a few percent of the total mass, 2) it may be rapidly destroyed by the Ne^{22} (α, n) Mg^{25} reaction. Furthermore, analysis of the material in the solar system shows that the Ne^{22}/Ne^{20} ratio is about 0.1. It seems rather difficult to assume a very different ratio for the cosmic average. A similar but even stronger case can be made against Ne^{21}.

In summary, the conclusions suggested in this note are the following:

1) The isotopes of neon are never produced abundantly in the hydrogen or helium burning phases.

2) The observational evidence on the planetary nebulae may be a confirmation of that statement.

3) Although the neon isotopes can be made in rather

specialized circumstances, it appears difficult to

understand why their cosmic abundance can be as high

as it is.